1

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

TASC

ONE JACOB WAY READING, MASSACHUSETTS 01867 (617) 944-6850

TR-3505

AN ACQUISITION STRATEGY COMPARISON MODEL (ASCM)

Volume II - Appendices

3 May 1982

The views, opinions, and findings contained in this report are those of the author(s) and should not be construed as an official Department of Defense position, policy, or decision, unless so designated by other official documentation.

Prepared Under:
Contract No. MDA903-81-C-0182
For
DEFENSE SYSTEMS MANAGEMENT COLLEGE
Fort Belvoir, Virginia 99060

Prepared By:
Larry Cox
Michal Bohn

Approved By:
Paul Martin
Gerald Atkinson
Jacques Gansler

THE ANALYTIC SCIENCES CORPORATION
1700 North Moore Street
Suite 1220
Arlington, Virginia 22209

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
An Acquisition Strategy Comparison Model (ASCM)
Volume I - Executive Summary and Report
Volume II - Appendices

5. TYPE OF REPORT & PERIOD COVERED
Final Technical Report

6. PERFORMING ORG. REPORT NUMBER
TR 3505

7. AUTHOR(s)
Larry Cox - (TASC)
Michael Bohn (TASC)

8. CONTRACT OR GRANT NUMBER(s)
MDA 903-81-C-0182

9. PERFORMING ORGANIZATION NAME AND ADDRESS
The Analytic Sciences Corporation
1700 North Moore Street, Suite 1220
Arlington, VA 22209

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Defense Systems Management College
Department of Research and Information
Fort Belvoir, VA 22060

12. REPORT DATE
3 May 1982

13. NUMBER OF PAGES
Vol I-65 Vol II-54

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

"A" Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Document provides a

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
ASCM
Acquisition Strategy Comparison Model
Acquisition Strategy Model
Multiattribute Model
Weapon System Acquisition Strategy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

~~A~~ detail of a prototype computerized model for acquisition strategy comparison. An interactive menu selection process is used to obtain a general description of the weapon system concept and program objectives. The model and the user then interact to successively reduce the number of strategy alternatives to a small set containing the preferred alternatives for a particular situation. ~~Prototype~~ model limited to two categories of weapon systems, tactical missiles and electronic subsystems. Volume II discusses the internal relationships between risk, time & cost used in the model.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

APPENDIX A
A DESCRIPTION OF INTERNAL RELATIONSHIPS

A.1 INTRODUCTION

All internal relationships included in this prototype model have their foundation in data analysis. This does not imply that all relationships are statistically valid. The amount and the quality of the data supporting the relationships vary greatly. In cases, some degree of statistical significance does exist. More frequently, data was sufficient only to identify trends and general relationships. From these identifiable trends, mathematical formulations were derived which captured these relationships. For the most part, the methodology adopted is a heuristic, empirical one, which lends itself to validation and modification through rigorous data analysis. That is to say, additional data can be used to accept, reject,or modify many of the postulated relationships.

A.2 DEVELOPMENT PHASES

A.2.1 Technical Risk Reduction

The input estimates of technical risk and their levels of confidence are transformed into a vector representing the probability distribution of risk for each category. The probability distribution is based upon the binomial distribution. The estimated level of risk determines the mean, and the level of confidence determines the dispersion

about the mean. The process used for accomplishing this transformation is arbitrary, but accomplishes the desired result of incorporating uncertainty into the risk assessment process.

The risk reduction matrices generated from the questionnaire (see Appendix E) constitute linear transformations or mappings. These risk matrices differ by risk category and strategy/phase alternative. Ordinary matrix multiplication results in a modified description of technical risk by risk category and by strategy alternative.

The set of risk vectors existing at the completion of Phase 2 (which are a function of risk category and development strategy) represents the probability distribution of technical risk remaining at the completion of FSD given a particular multi-phase development strategy. These are used later in the calculation of probabilities of success.

A.2.2 Time and Cost

Since the results of the data analysis indicated a high correlation between the cost of pursuing a phase alternative and the level of risk at the beginning of that phase, this phenomenon was included in the model. The cost of pursuing each phase alternative is described in terms of a normal (Gaussian) probability distribution with mean and standard deviation determined from the data analysis after removing the influence of technical risk. The mean and standard deviation are then weighted by the three probability distributions of risk calculated for the beginning of that phase alternative. Each risk category received equal weighting. Since the phase alternatives reduce risk differently, the cost associated with pursuing each alternative varies accordingly (in addition to the differences in the cost which are a function of phase alternative only).

The time required to complete each phase alternative is represented as a normal probability distribution with mean and standard deviation derived from the data analysis. Little correlation between time and risk was evident in the data.

The time and cost associated with the complete development effort (all phases) are derived from the probability distribution of the constituent phases according to standard rules of probability theory. The probability distributions of time are used in calculating the probability of success, and the probability distributions of cost are used in the relative cost comparisons.

A.2.3 The Effect of Concurrency

The degree of concurrency impacts not only the risk reduction matrices derived from the questionnaire described in Appendix E, but two additional areas as well.

The first area affected is time to Initial Operational Capability (discussed in Appendix D). The higher the degree of concurrency, the sooner IOC is realized. A normal probability distribution is assumed with the mean and standard deviation determined from data analysis.

The second area is the effect on production options. The model assumes that it is not possible to develop a second production source during the period of concurrency when FSD and early production activities overlap. The higher the degree of concurrency, the longer the delay before a second production source becomes feasible. This degree of overlap between FSD and production was derived from programs employing

concurrency and is represented in the model by a normal probability distribution with mean and variance determined from the data analysis.

A.3 PRODUCTION PHASE

The majority of the relationships incorporated into the production phase stem from the Production Cost Analysis Methodology (PCAM) previously developed by TASC. Data collected during this effort, combined with data previously analyzed, were used to generate two generic sets of PCAM parameters, one suitable for tactical missile systems and one suitable for electronic subsystems. A detailed discussion of PCAM is provided in Appendix B.

There is one additional aspect relating to production cost that became evident during the data analysis effort. That aspect concerns the effect of competitive FSD on subsequent production cost. Although the amount of supporting data is currently small, there is clear evidence that competition during FSD suppresses (compared to single source FSD) subsequent production costs, at least for the first few years. This concept is incorporated in the model, but additional research is warranted.

A.4 PROBABILITY OF SUCCESS CALCULATION

The probability that a given acquisition strategy meets the IOC requirement at a level of design stability is the combination of the set of risk vectors existing at the completion of FS (see s^ tion A.2) with the probability that the multi-phase dev lop ent strategy can be completed. The

set of risk vectors are used as conditional probabilities representing the probability that technical risk is reduced to the specified level, given the development phase is completed.

The calculation further assumes that the risk reduction process across the three categories of technical risk are independent. It is recognized that a certain amount of synergism exists; however, arriving at an appropriate methodology for including these perceived interdependenices is a non-trivial undertaking. TASC recommends that this research be performed in order to add increased validity and realism to the model.

Under these assumptions, the probability of success is calculated by multiplying all constituent probabilities. The principal inadequacy resulting from this approach is that the probabilities of success appear lower than expected. They appear adequate, however, as relative indicators which is their purpose.

A.5 DOMINANCE ANALYSIS

At this point in the evaluation process, ten principal attributes describe each strategy: six probabilities of success (3 levels and two IOC times), relative development cost, and relative total program cost for three inventory estimates. In this form, they are all on a scale from zero to one. For the probabilities of success, greater is superior; for the relative cost estimates, smaller is superior.

The first step in the dominance analysis is a pairwise dominance comparison incorporating a "closeness criteria". For a closeness parameter of α (.03, .05, and .07 are all used),

strategy A is said to dominate strategy B if and only if (1) no attribute of B is superior to the corresponding attribute of A by an amount as great as α, and (2) at least one attribute of A is superior to the corresponding attribute of B by an amount at least as great as α. From this comparison, an n x n matrix (where n equals the number of strategies being compared) is produced for each α. If (δij) denotes the matrix, then δij is 1 if and only if strategy i dominates strategy j; otherwise, $\delta ij = 0$ (note that $\delta ii = 0$ for all i).

Note that with this "soft" aspect of dominance, it is possible for strategy A to dominate strategy B, for strategy B to dominate strategy C, and for strategy C to dominate strategy A. Because of this, a strategy must pass two criteria to be considered to be dominated by the set of strategies and eliminated from further consideration: (1) it must be dominated by at least one strategy in the set, and (2) it must not dominate any other strategy in the set. Any strategy which meets both criteria can be considered as "inferior" or a "second-best" option and eliminated from further consideration.

If one or more strategies are eliminated in this fashion, the subset of strategies remaining constitute a new set of strategies for the "set comparison", and the process can be repeated. The entire process is iterated until no further strategies pass the two criteria. The resulting set of strategies then contains no "second-best" options.

This process is performed for three "closeness criteria". The choice of the resultant set displayed is made arbitrarily by a heuristic algorithm. If a more stringent closeness criteria than the one selected for display would result in additional strategies being eliminated, a message to this effect is printed.

As mentioned in the report, the process should be considered experimental. Further research and analysis into the implications of this procedure, as well as possible alternative methodologies, is justified.

APPENDIX B

THE TASC PRODUCTION COST ANALYSIS METHODOLOGY

The TASC Producton Cost Analysis Methodology (PCAM) integrates data analysis with management analysis and computer models. It is used to assist government program personnel in assessing the relative costs and benefits of alternative acquisition approaches. A conceptual description of PCAM is shown in Figure B-1.

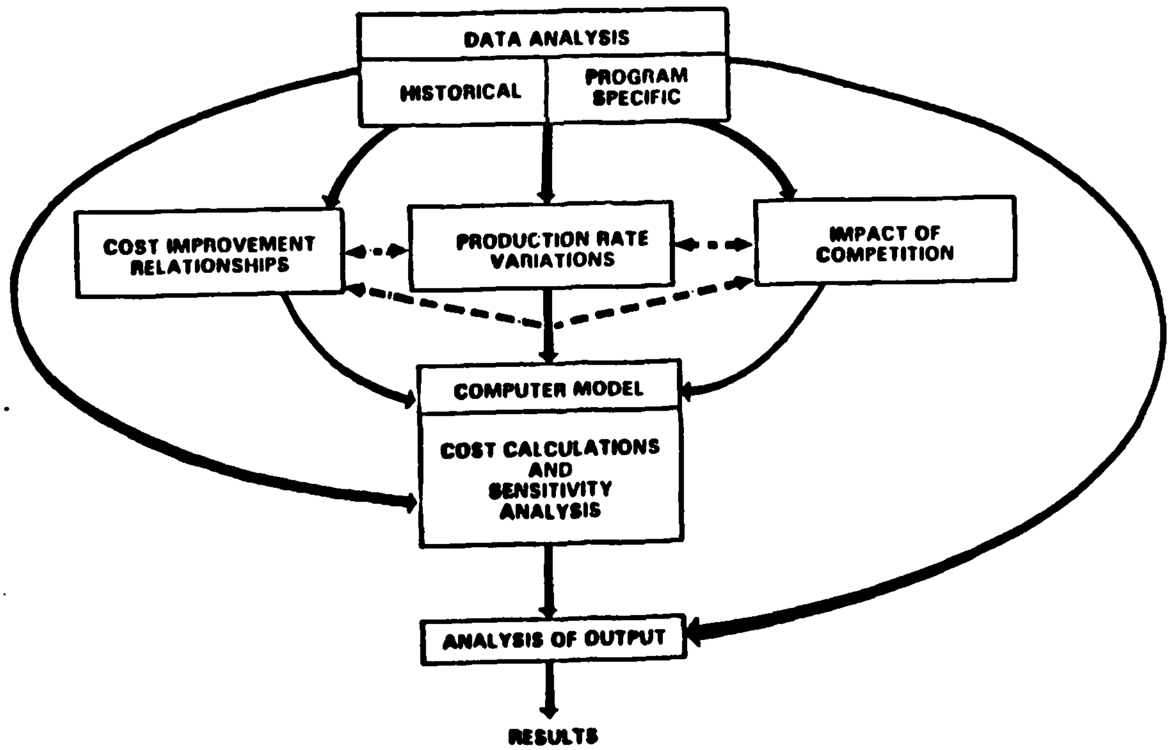

Figure B-1 PCAM Description

B.1 DATA ANALYSIS

TASC's data analysis considers both program specific data and historical data on similar programs. Consideration of program specific production parameters enables TASC to tailor the methodology to the unique needs of a particular program. Data on similar programs is analyzed to establish a historical basis for the cost estimation. TASC uses several computer programs to assist in analyzing the raw data. These incorporate techniques such as linear regression and least squares curve fitting. The results of the data analysis are used to identify cost improvement curve relationships, production rate characteristics, and the impact of competition.

B.2 COST IMPROVEMENT CURVE

A cost improvement curve reflects the relationship between the unit cost (or unit price) of an item and the quantity of the item produced. An "80 percent" curve is one in which a doubling of output drives unit cost down to 80 percent of its initial value. That is, the cost of the 2Nth unit is 20 percent less than the cost of the Nth unit. Graphically displayed in Figure B-2 is a cost improvement curve in standard form.

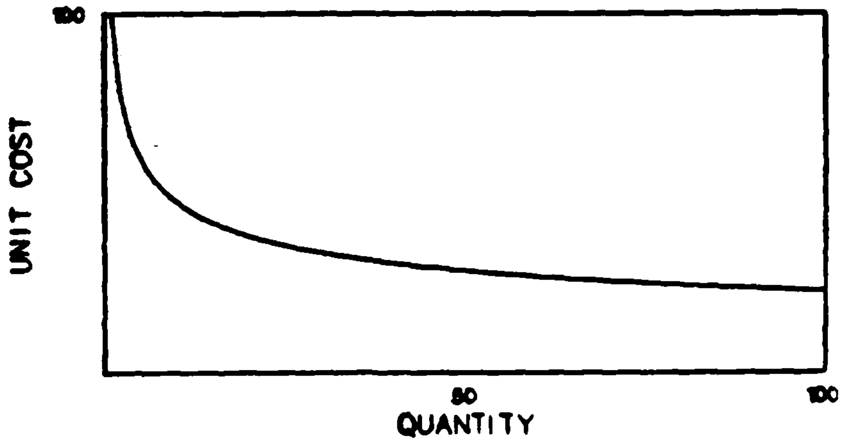

Figure B-2 Cost Improvement Curve in Standard Form

Frequently, cost improvement curves are depicted in logarithmic form (the logarithm of unit cost as a function of the logarithm of cumulative quantity) producing the linear relationship display in Figure B-3.

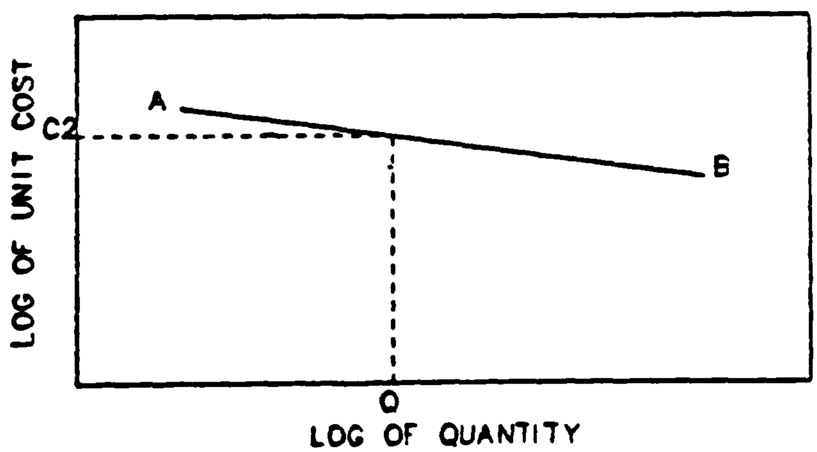

Figure B-3 Cost Improvement Curve in Log-Linear Form

B.3 COMPETITION

TASC has identified two effects that the introduction of competition has on the unit cost improvement curve. One of these is a downward shift in the curve resulting in an immediate decrease in unit costs. The other is a rotation of the curve, or an increased rate of cost improvement for all future units produced. Figure B-4 illustrates the total effect of competition on the log-linear form of the cost improvement curve.

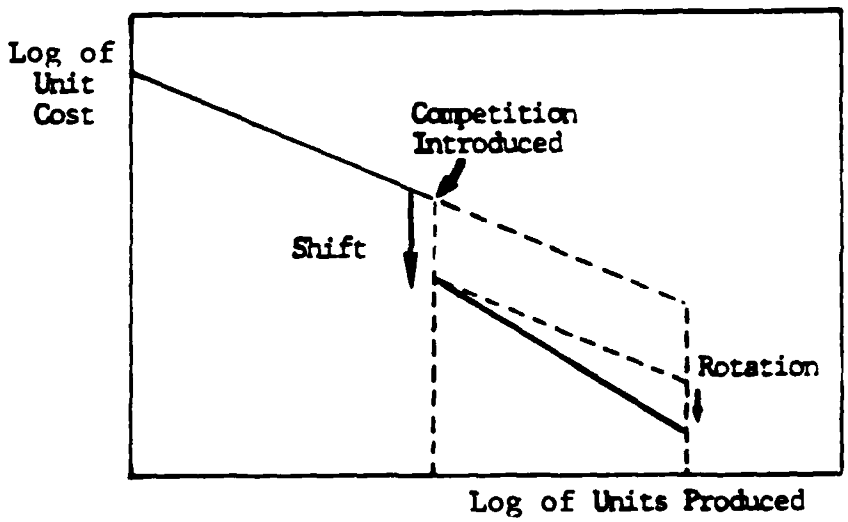

Figure B-4 Benefits of Competition

TASC's prior analysis of several tactical missile programs clearly demonstrated the shift and rotation of the cost improvement curve due to competitive forces. Recent

analysis has demonstrated that the magnitudes of the shift and the rotation vary. These variations are highly correlated both with the number of units produced on a non-competitive basis and with the slope of the non-competitive cost improvement curve. From this, TASC hypothesized a theoretical framework which correlates with the observed results as shown in Figure B-5. The hypothesis incorporated an "optimal" or "best" cost improvement curve that one might observe if the manufacturer were under continuous competitive pressure from the outset.

Detailed analysis was conducted on five missile cases to test the hypothesized framework. The results of the analysis revealed that, on the average, the "optimal" curve could be achieved with no shift in the first unit cost and a four percent rotation of the cost improvement curve at the origin,

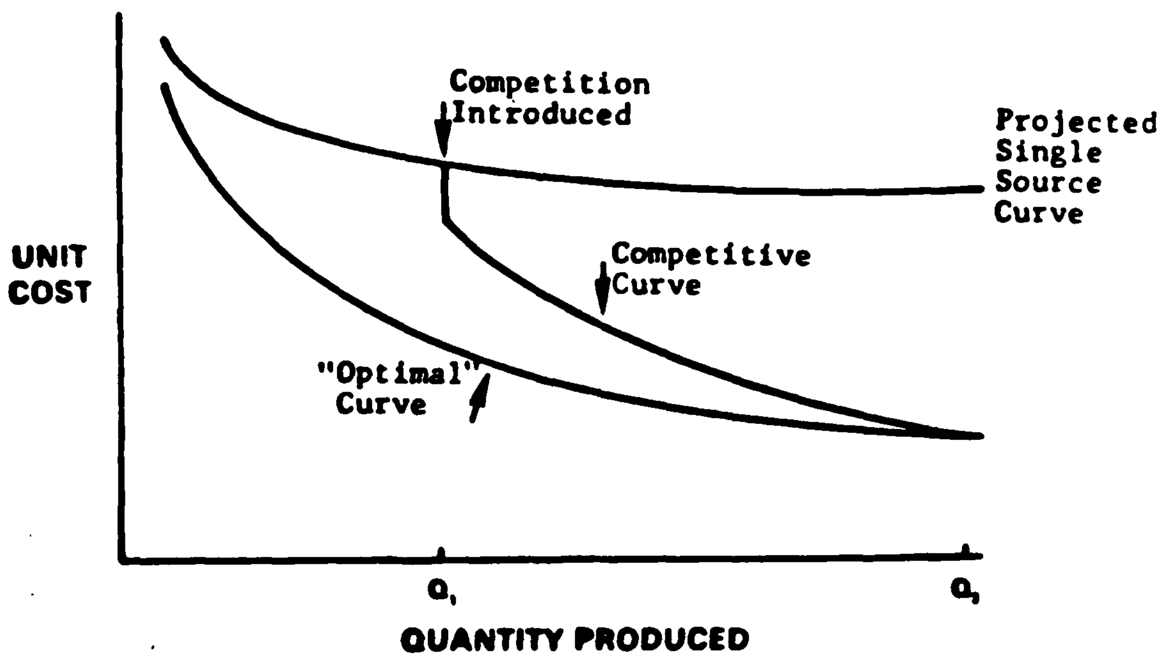

Figure B-5 TASC Framework: The Impact of Competition

assuming the manufacturer was under continuous competitive pressure. Applying linear regression with the non-competitive slope as the independent variable and the optimal competitive slope as the dependent variable yields a significant correlation coefficient of .995 for the five missile cases examined.

The data analysis demonstrated that the flatter the non-competitive curve and the larger the quantity produced prior to competition, the greater the potential for unit cost reductions from the original producer once competition is introduced. The observed shift and rotation of the original producer's cost improvement curve resulting from competitive pressure can be characterized as "making-up" for cost improvements which were possible but were unrealized due to the absence of competitive pressure. The earlier competitive pressure is applied during the production phase, the earlier the producer attains his optimal curve, and the greater are the total savings due to competition.

The obvious source of competitive pressure is price competition by the second source. TASC's continuing analysis has demonstrated that the relationships between the first and second producers' cost behavior are as displayed in Figure B-6.

The first source had a first unit cost represented by point A and followed the cost improvement curve so designated. After Q_1 units were produced by the first source, a second source began production with a first unit cost of B and followed the cost improvement curve represented by the dashed line. In each of the five missile cases, B was less than A and greater than C, the unit price achieved by the first source after Q_1 items has been produced. Also in each of the five cases, the slope of the second source's cost improvement

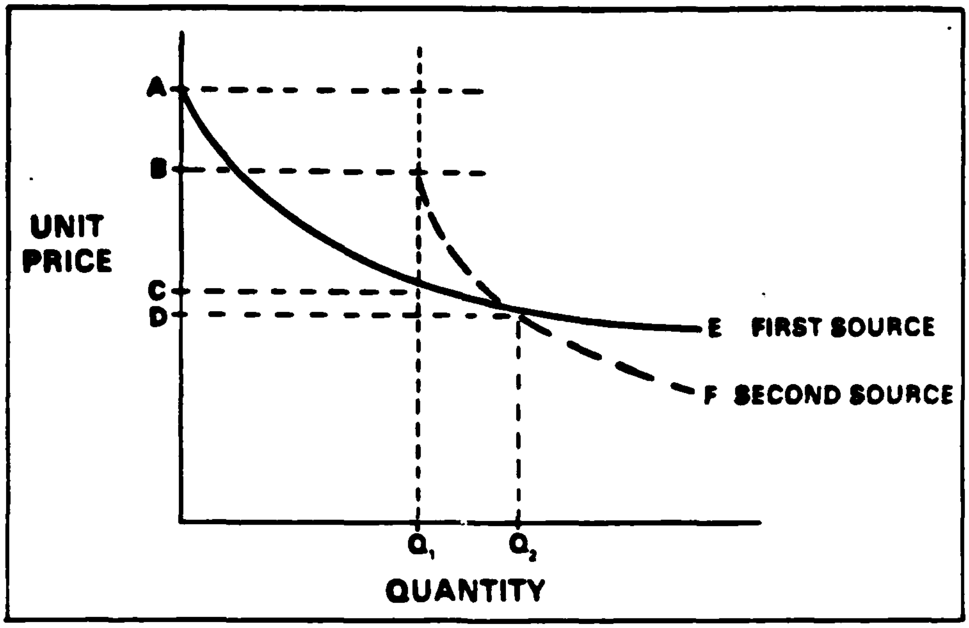

Figure B-6 Cost Improvement Curves of First and Second Source

curve was steeper than the slope of the first source's cost improvement curve. On the average, the second source cost improvement curves were 5 percent steeper than the first source curves, and the first unit cost of the second source (B) was 25 percent less than the first unit cost of the first source (A).

For the cases analyzed, the implication is that the second source begins production at, or very near, his "optimum" cost improvement curve. This enables the second source to rapidly approach cost parity with the first source during the production of his learning quantities. Following the learning buys, competition is introduced and the first source shifts and rotates his cost improvement curve by amounts sufficient to bring his price slightly below that of the second source.

B.4 PRODUCTION RATE VARIATIONS

Prior research into the effect of production rate on unit cost has shown that unit cost frequently decreases with increasing production rate in a form virtually identical to that of cost improvement curves. However, traditional economic theory says that there are both economies and diseconomies of scale, and the curve should be U-shaped if one assumes production capacity to be fixed. The TASC formulation embodies both of these considerations as depicted in Figure B-7.

The formulation assumes the existence of an optimum (most cost efficient) production rate, denoted R_0 in Figure B-7. Typically, a manufacturer will arrive at this rate in an attempt to maximize profits by considering his facility limitations, capital investment requirements, anticipated quantities to be procured by the government, the rates of procurement, and other requirements specified by the government.

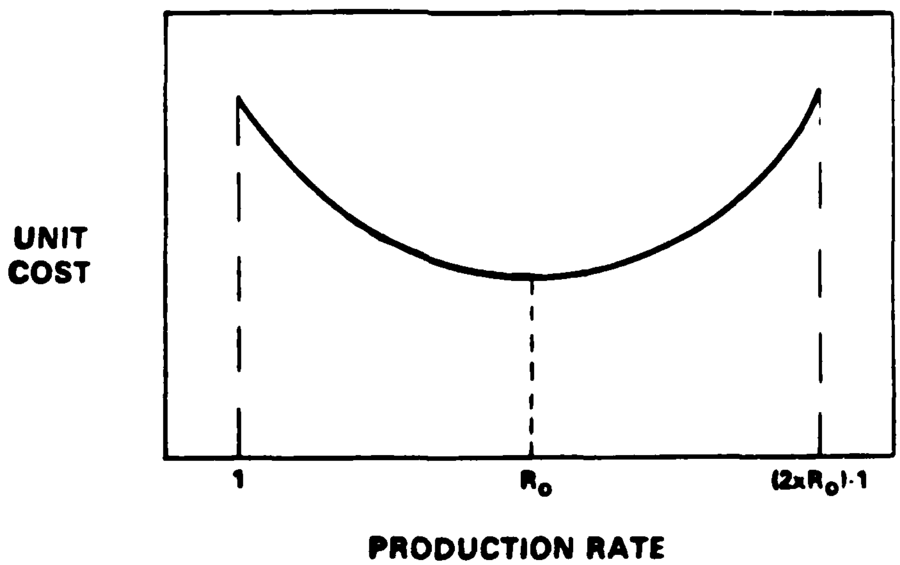

Figure B-7 Effect of Production Rate on Unit Cost

It was further assumed that the curve should be symmetric about R_O. Thus, production costs are minimized when the production rate is equal to R_O, and increase as one deviates from R_O in either direction. This formulation imposes the restriction that the maximum allowable production rate is $(2 \times R_O)-1$. For a manufacturer to produce at a higher rate, the production capacity would have to be expanded, thus producing a new R_O.

It should be noted that the symmetric shape of the production rate curve is an assumed shape. Other authors on the subject may contend that a curve of one shape (possibly the one chosen) should be used as one increases production rate up to the optimal value, and that a curve of a different shape be used as one increases production rate above the optimal value. TASC's data analysis has indicated that the specific shape of the production curve is unique for each program, determined by particular program and contractor characteristics. The flexibility of TASC's methodology enables it to incorporate these unique aspects. Detailed analysis of the five missile cases has indicated that the general symmetric production rate curve can be employed to predict production costs within one percent of actual costs.

B.5 COST CALCULATIONS

Combining the effects of both competition and production rate into a unified model results in the TASC Cost Improvement and Production Curve (CIPC) model. Figure B-8 displays the resulting relationships graphically.

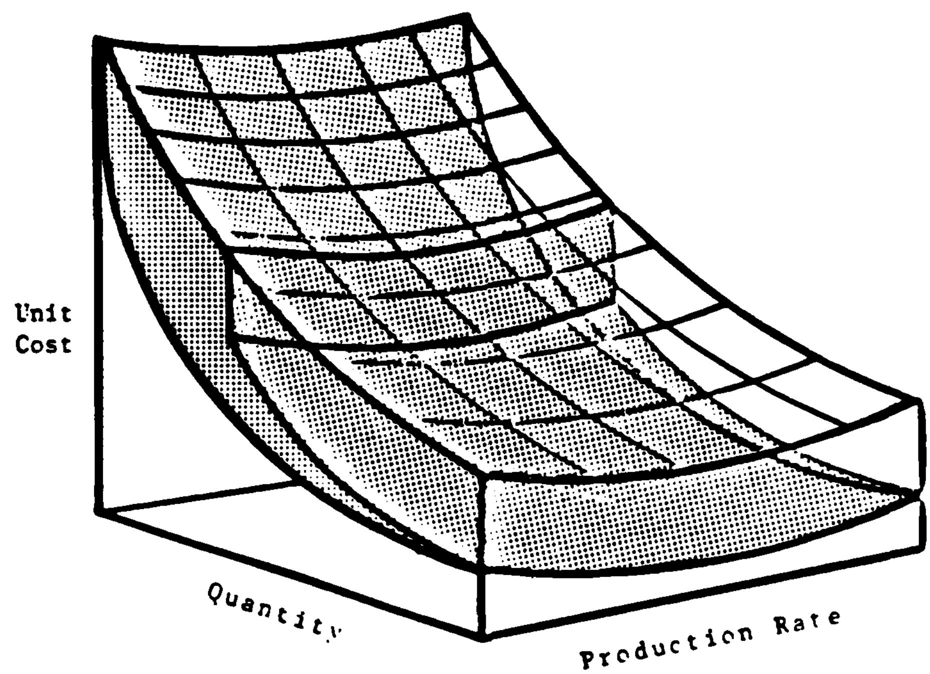

Figure B-8 TASC Cost Improvement and Production Curve Model

Cost estimates for alternative acquisition approaches for individual programs are generated using the CIPC model. It simultaneously considers cost improvement curve effects, production rate variations and the impact of competition on the recurring production costs of weapon systems and subsystems. The basic formulation considers <u>unit production cost as a function</u>

of both total quantity produced and the production rate. Mathematically, this is expressed as follows:

$$Z = AX^{B}Y^{C}$$

where

Z = unit cost of the X^{th} item produced

A = constant (sometimes referred to as T_1 or "first unit cost")

X = cumulative quantity produced

B = coefficient which describes the slope of the quantity/cost curve

Y = (proxy) production rate in effect

C = coefficient which describes the slope of the rate/cost curve.

B.6 MANAGEMENT ANALYSIS

Sensitivity and management analyses can be performed to assess alternative acquisition strategies in relation to unique program characteristics. Factors such as timing of competition, cost, schedule and technical risk, product improvement, lower tier contractor development, and contracting alternatives are frequently considered. This ensures that the analysis considers all the factors that are relevant to a particular program's acquisition approach evaluation. In turn, the results of these analyses enable program personnel to make informed decisions when selecting an acquisition approach.

B.7 SUMMARY

The TASC PCAM is a results-oriented acquisition research and analysis methodology that incorporates detailed data analysis with management analysis, computer models and cost estimating. PCAM was developed to assist government program offices in assessing the relative costs and benefits of alternative acquisition approaches. PCAM is a dynamic methodology that enables TASC to address the unique requirements of a particular program as well as incorporate the changing characteristics of the DoD acquisition process.

PCAM is a proven analytic tool. It has been successfully used to support programs such as the Cruise Missiles, AMRAAM, and the Global Positioning System User Equipment. PCAM's dynamic, practical, and results oriented nature makes it applicable to any major system or subsystem acquisition program.

APPENDIX C
DATA COLLECTION

The development of the prototype model required a large and varied amount of data covering the four acquisition phases. Two major categories of data, program history and judgement data, were required. The first category centered on specific program parameters:

- Strategy used in acquisition phase
- Length of phase
- Cost of phase
- Risk levels prior to Phases 1 and 2
- Interim between start of Phase 2 and IOC
- Overlap between production and development
- Second source start-up costs
- Learning curve parameters
- First unit cost
- Production rate parameters.

The second category dealt with measuring the ability of a selected strategy to reduce technical risks to a manageable level. Each category had a different data collection process, level of difficulty, and degree of success.

C.1 PROGRAM HISTORY COLLECTION

The data collection effort of selected program histories was limited by the following factors:

- Scope of the model
- Collection process
- Quality and quantity of data.

Each factor individually and collectively affected the sources and types of data collected.

The scope of the prototype model was limited to tactical missile systems and military electronics subsystems. These categories were selected because of their broad base within the military community. For example, both categories of systems are developed and produced in all three services: thus, the model would be relevant to a large number of sectors in each service. It was also felt that the extensive use of electronic subsystems within tactical missiles provided an interdependent relationship that would be useful in data collection and validation of results. In addition, TASC's previous research efforts had resulted in an accumulation of missile and electronics production cost data. It was felt that this existing data would reduce the required data collection effort.

The intent of the development effort further limited the scope of the data collection effort. The goal of the phase was to produce a model capable of successfully demonstrating the ability to model the acquisition environment in a useful way. Thus, efforts were limited to levels necessary to demonstrate the model's feasibility. Additional data would greatly enhance the rigor of estimating the model's parameters.

The data collection process followed a long and somewhat tedious path depicted in Figure C-1. As shown, data leads were sought, and after a period of time, usually located. Typically, a number of calls were required to locate a knowledgeable and responsible individual with control over access to the data. After the request for access was verbally agreed to, a formal request from DSMC was required. After this request had worked its way through the chain of command to the person coordinating our request, an appointment could be made and clearances sent. This process spanned approximately two to six months and required conversations with a large number of people to obtain necessary permission. The length of this process dominated the process and highlighted the quantity and quality of data resulting from each iteration.

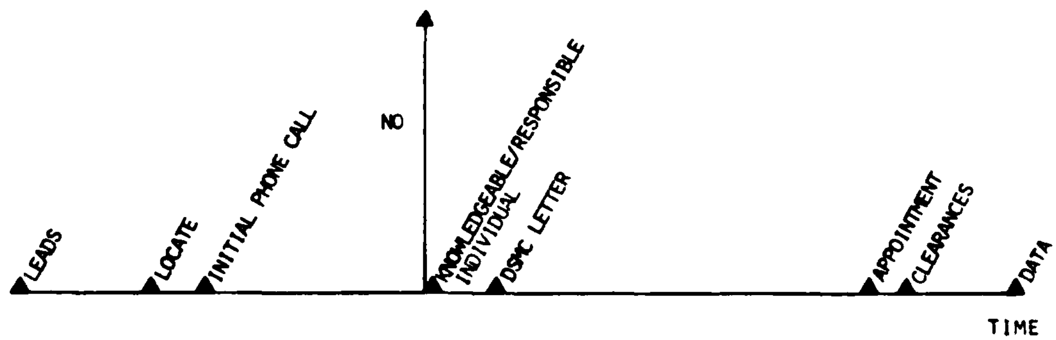

Figure C-1. Data Collection Process

The original data collection effort was directed towards locating and accessing individual missile and electronic subsystem program offices. The objective was to obtain a basically complete and useful history of the specific program through interviews and examination of program records and documents. The quality and quantity of data obtained in this

way varied greatly. In all cases, the program offices kept records of the acquisition phase currently in progress. Some maintained records of prior phases ranging from a one paragraph history to major summaries. Thus, in most cases, only one phase was sufficiently covered, with additional effort required to locate and obtain information about earlier activities.

The length of time required to obtain the individual program office data limited the amount of data that could be collected. In an effort to increase the volume of data, collection efforts were redirected towards the Historical Offices of the various missile and electronics commands (while still following up on prior program office contracts). One of the primary functions of these offices is to collect, analyze, and synthesize weapons development and production histories from concept exploration to end of production. Each office contained this information on many programs, thus reducing the length of data collection per program. In addition, these data were the most complete source of individual program information. Their only drawbacks were the ages of the programs summarized.

In addition to program office and Historical Office data, two other less significant data sources were tapped. The Selected Acquisition Reports (SAR) collected on major programs could be used alone or as supplements to other information. More research in this area would be beneficial. The second source came from prior studies and analyses. These also could be used alone: for example, TASC's production rate work, or as a supplement, SAI's collection of R&D cost/time summaries.

In sum, the data collected from these four sources was adequate to develop the specific program parameters necessary to the prototype model. Information on alternatives was collected from thirty-seven programs for one to four phases (see Table C-1). In addition, other program histories were collected that were insufficient for full-phase analysis but lent insight into the analysis and estimation of the model parameters.

C.2 RISK-REDUCTION MEASUREMENT

During the feasibility study, the method of quantifying risk reduction was developed. Given this basis, a questionnaire was chosen as the best way of obtaining the subjective assessments from knowledgeable individuals. The initial analytic approach used The Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty of the University of Pittsburgh. This method proved to be much too difficult for most individuals not familiar with AHP or the definitions embodied in the questionnaire. After numerous iterations to reduce the complexity of the questionnaire, the method was abandoned.

The method finally used is shown in Appendix D. While this new questionnaire was simpler than the first it was still extremely difficult for the respondents unless verbally administered to them. The type of information needed limits the amount of simplification available. The prototype model would benefit from the refinement resulting from additional questionnaire administration.

TABLE C-1
PHASE DATA BY SYSTEM

System	Phase 0	Phase 1	Phase 2	Phase 3
FAAR		X	X	X
Chaparrel	X	X	X	X
Interim Little John	X		X	X
Matador		X	X	X
Hound Dog				X
Pershing I				X
Rascal	X		X	X
Improved Honest John	X		X	X
IR MAVERICK		X		
Quail		X		
Corvus		X		
Nike Hercules		X		
Pershing 1a		X	X	
Basic Honest John	X	X	X	
Radar Jammer	X	X		
Eagle		X		
Plato		X	X	
SIDS			X	
Shrike			X	X
Standard Missile				X
Basic Hawk				X
Laser Maverick		X		
Sparrow		X	X	X
Maverick		X	X	X
Redeye			X	X
Sidewinder	X		X	X
Bullpup				X
TOW	X	X	X	X
Little John	X		X	X
Aerno 60-6402				X
TD-204				X
TD-660				X
TD-202				X
MD-522				X
ASW-27				X
AN/APM-123				X
TD-352				X

APPENDIX D
DATA ANALYSIS

The purpose of the data analysis was to estimate the model parameters required to describe each strategy alternative for each of the four acquisition phases. Primary emphasis was placed on calculating these parameters from collected program histories. For those cases with little or no data, these strategy parameters were estimated from the parameters derived from the program data. The basic methods used to derive the necessary parameters were different for the development phases than for the production phase. The methodology and results follow.

D.1 DEVELOPMENT PHASE ANALYSIS

The first step in the analysis was to determine the strategy alternatives used throughout the program and their approximate start and end dates. The selection of the types of strategy alternatives was based on the program strategy alternatives described in Chapter Two of the feasibility study (TR-1375). Descriptions of program actions and plans recorded in program files, as well as outside discussions found in various journals and other publications, were compared to these definitions. The best descriptive fit was then chosen. Estimation of phase start and end dates was made in a number of ways. In later weapons programs, DSARC or individual service review dates were available, and used for the start and end dates. In earlier programs not covered under this review process, start and end dates were based on contractual information, program memoranda, proposed schedules and plans, and/or

activity descriptions. Another time parameter needed was the date of initial operational capability (IOC). In most cases, an IOC date was included in program documentation. Where no record of an actual IOC date was available, IOC was estimated to be twelve months after first production delivery. The length of each phase alternative was calculated in months from the start and end dates. Time to IOC was described in months from start of Phase 2.

After delineating each program by length and type of activity, the cost associated with each strategy alternative was determined. In some instances, cost records were available by fiscal year and type of money. These monies were converted to FY80 dollars and aggregated over the correct phase of the program. In other programs, where this type of information was not available or incomplete, contract dollars and/or SAR records were used. These monies were aggregated into the proper program phases by dates and listed requirements.

An additional piece of required data was the risk level prior to Phases 1 and 2. Using the risk categories and definitions developed for the questionnaire, each phase alternative was assigned a risk level based upon technical descriptions and reports of program personnel and knowledgeable individuals outside the program.

The results of the above analyses were collected into sets of cost, time, and risk for each strategy alternative represented by data. A mean and standard deviation of time and cost per unit of risk were calculated. Those strategy alternatives not represented in the data sample were then estimated from these points. A good example of a well

represented strategy alternative was the Phase 1 - Prototype/Single Source alternative. Table D-1 shows the data and results for this alternative for tactical missiles.

TABLE D-1
PHASE 1 - PROTOTYPE/SINGLE SOURCE

Case	Months	Cost (MIL 80$)	Risk	Cost/Risk
1	60	25.96	4	6.49
2	16	12.32	2	6.16
3	60	106.62	6	17.77
4	24	64.70	6	10.78
5	49	60.11	4	15.03
6	17	11.96	2	5.98
7	62	74.75	5	14.95
Mean	41.14	50.92		11.02
S.D.	21.14	32.90		4.90

D.2 PRODUCTION PHASE ANALYSIS

Three types of parameters were required for each alternative in the missile and electronic subsystem categories. These parameters are a cost improvement curve rate, production rate, and first unit cost. In addition, two parameters, optimal curve rate and start-up costs, were necessary to represent those alternatives having a second source.

The first three parameters are derived from program lot quantities and costs using TASC's Learning Curve and Production Rate (LCPR) Model. LCPR is TASC's surface fitting

model that solves for cost improvement rate, production curve rate, and first unit cost simultaneously. Using exponential formulations, LCPR reaches a solution based on a least-squares fit. It obtains this by using a log-linear solution as an initial starting point and proceeding through successive iterations based on a generalization of Newton's method for finding the roots of a non-linear function. The cost improvement curve and production rate parameters were then combined with other previously computed points, divided into groups of similar strategy alternatives, and their average computed.

Derivation of the optimal curve was based on prior TASC analysis. TASC has found that under competition, production lot costs are below the normal sole source curve. In general, the optimal curve represents the learning curve a producer must follow to reach these lower lot costs given a sole source starting point. The linear relationship between the optimal curve and the sole source curve found in previous analysis was applied to the sole source learning curve average to obtain the optimal curve for this analysis.

Start-up costs were assumed to be any costs of technology transfer, new tooling, and learning quantities. While few complete data points were available, a trend emerged when start-up costs were compared to their respective first unit costs. This relationship was used to estimate start-up costs in missile systems.

APPENDIX E
RISK ASSESSMENT QUESTIONNAIRE

A key component of the prototype model is a relative measure of how acquisition strategies reduce program risk. This was accomplished through the use of a questionnaire in which an individual knowledgeable in weapons acquisition rated the ability of Phase 1 and 2 strategies to reduce given levels of risk to selected levels of risk.

E.1 QUESTIONNAIRE

The attached questionnaire was completed by a limited number of individuals with direct knowledge of missile and/or electronics acquisition.

E.2 DATA ANALYSIS

Due to the limited response, analysis was based upon the highest and lowest ratings given for each question, rather than an average of all responses. More data would allow a more rigorous approach. The average of these two points was normalized to 1.00. See Table E-1 and Table E-2. This gives the probability of success of reducing risk from a perceived pre-phase status to a desired-end-phase status for the general strategy alternatives.

This information was mapped onto a 10 x 10 matrix for each strategy alternative and each level or risk (see Figure

E-1). These mappings revealed a similar trend in every alternative and category. All mappings showed approximately the same probability of reduction from risk level 5 to risk level 3 as from 7 to 5; and the same from 7 to 3 as 9 to 5. Given this pattern, it was assumed to hold for all pre-phase to end-phase risk levels. The risk reduction probabilities from any risk level 1 through 10 to any lower-risk level were estimated from these points (see figure E.2). A similar mapping for each alternative in Phases 1 and 2 for each of the three levels of risk was developed and incorporated into the prototype model.

TABLE E-1

DEMONSTRATION AND VALIDATION - RISK REDUCING CAPABILITY

RISK CATEGORY	RISK LEVELS		ALTERNATIVES		
	Perceived Pre-Phase Status	Desired End-Phase Status	Contract Definition	Subsystem/ Component Development	System Prototype
TECHNOLOGY ADVANCE	Total redesign	Moderate development required	.31	.50	.87
	Major development required	Moderate development required	.43	.68	.93
	Total redesign	Minor development required	.25	.37	.75
	Major development required	Minor development required	.37	.56	.81
	Moderate development required	Minor development required	.43	.81	.93
SYSTEM INTEGRATION	All interfaces must be totally redesigned	At least one interface needs major redesign	.24	.56	.81
	Several interfaces need major redesign	At least one interface needs some redesign	.37	.68	.93
	All interfaces must be totally redesigned	At least one interface needs some redesign	.18	.43	.75
	Several interfaces need major redesign	At least one interface needs some redesign	.31	.56	.81
	At least one interface needs major redesign	At least one interface needs some redesign	.56	.74	.93
SOFTWARE DEPENDENCY	Total disruption	Moderate disruption	.31	.43	.[illegible]2
	Major disruption	Moderate disruption	.43	.62	.81
	[illegible]al disruption	Slight disruption	.18	.37	.56
	Major disruption	Slight disruption	.37	.50	.68
	Moderate disruption	Slight disruption	.50	.63	.87

TABLE E-2

FULL-SCALE DEVELOPMENT - RISK REDUCTION CAPABILITY

RISK CATEGORY	RISK LEVEL		ALTERNATIVES		
	Perceived Pre-Phase Status	Desired End-Phase Status	Full Concurrency	Partial Concurrency	Incremental
TECHNOLOGY ADVANCE	Major development required	Minor development required	.31	.56	.75
	Major development required	No new knowledge required	.25	.37	.62
	Moderate development required	Minor development required	.43	.62	.87
	Moderate development required	No new knowledge required	.31	.50	.75
	Minor development required	No new knowledge required	.38	.74	.93
SYSTEM INTEGRATION	Several interfaces need major redesign	At least one interface needs some redesign	.37	.62	.81
	Several interfaces need major redesign	No redesign required	.25	.44	.68
	At least one interface needs major redesign	At least one interface needs some redesign	.50	.68	.87
	At least one interface needs major redesign	No redesign required	.37	.50	.68
	At least one interface needs some redesign	No redesign required	.50	.62	.68
SOFTWARE DEPENDENCY	Major disruption	Slight disruption	.31	.49	.75
	Major disruption	No disruption	.25	.31	.56
	Moderate disruption	Slight disruption	.43	.62	.81
	Moderate disruption	No disruption	.25	.43	.68
	Slight disruption	No disruption	.37	.68	.87

Pre-phase Risk Level

	1	2	3	4	5	6	7	8	9	10
1	1									
2		1								
3			1							
4				1						
5			.87		1					
6						1				
7			.68		.81		1			
8								1		
9			.56		.62				1	
10										1

Figure E-1: Software Dependency/Prototype - Probability of Risk Reduction/Selected Levels

Pre-phase Risk Level

	1	2	3	4	5	6	7	8	9	10
1	1									
2	.95	1								
3	.85	.95	1							
4	.75	.85	.95	1						
5	.65	.75	.85	.95	1					
6	.57	.65	.75	.85	.95	1				
7	.5	.57	.65	.75	.85	.95	1			
8	.4	.5	.57	.65	.75	.85	.95	1		
9	.3	.4	.5	.57	.65	.75	.85	.95	1	
10	.1	.3	.4	.5	.57	.65	.75	.85	.95	1

Figure E-2: Dependency/Prototype - Probability of Risk Reduction/All Levels

RISK ASSESSMENT QUESTIONNAIRE

ATTACHMENT

INSTRUCTIONS

INTRODUCTION

We Need Your Help

The Analytic Sciences Corporation (TASC), under contract to the Defense Systems Management College (DSMC), is developing an analytic model for use in acquisition strategy decisions. The initial objective is an effective teaching aid for evaluating strategy options in the research, development, and production phases of weapon systems acquisition. Should this prove successful, a long-term objective is an acquisition strategy decision aid for program managers.

Included in the analytic model is the concept of technical risk through various phases of the acquisition process. One method of quantifying technical risk is through a subjective assessment by a broad range of system acquisition experts. Several methods were considered before a straightforward rating of each alternative was chosen.

This questionnaire is being distributed to persons knowledgeable in the acquisition field. After receiving their opinions, the results will be integrated to determine relationships among acquisition strategies, as they pertain to risk. Your assessment of the situations described in this questionnaire is very important and will greatly enhance the validity of the research effort. Specific questions or comments regarding the questionnaire should be addressed to Mr. Larry Cox or Ms. Michal Bohn of TASC at (703) 558-7400. Comments or questions regarding the general nature of this research effort should be addressed to Mr. John McKeown of DSMC at (703) 664-5783 (Autovon 354-5783).

OBJECTIVE

The objective of this questionnaire is to collect the basic research data to help determine how selected acquisition strategies reduce certain aspects of technical risk associated with weapon system and subsystem development.

APPROACH

In this questionnaire, you are asked to consider strategy alternatives under given conditions of technical risk and rate the strategy's ability to reduce the given technical risk. A discussion of the concepts and terminology used in this questionnaire follows.

ACQUISITION PHASES

Our research work follows Department of Defense Directive 5000.1, subject Major System Acquisition, dated March 19, 1980 which defines the four principal phases associated with the acquisition process of major defense systems as:

Phase 0: Concept Exploration -- includes solicitation and exploration of alternative system concepts.

Phase 1: Demonstration and Validation (D&V) -- also referred to as Advanced Development.

Phase 2: Full-Scale Development (FSD) -- also referred to as Engineering Development -- includes limited production for operational test and evaluation.

Phase 3: Production and Deployment.

One of the major objectives of Phase 1 and Phase 2 is the reduction of technical risks or uncertainty to an acceptable level. Only these two phases are addressed in this questionnaire.

STRATEGY ALTERNATIVES

In each of the two phases, alternative acquisition strategies are available. The options of interest in this questionnaire have been summarized into three alternatives during Phase 1, D&V, and three alternatives during Phase 2, FSD, as follows:

PHASE 1: DEMONSTRATION AND VALIDATION (D&V)

Alt 1: Contract Definition - Short, intense planning and evaluation to determine cost, schedule, performance specification, management technique, etc., for FSD phase.

Alt 2: Subsystem and Component Development - Critical elements of a system are developed and major subsystems designed and tested.

Alt 3: System Prototype - Design, build, and test proposed end item (preproduction prototype).

PHASE 2: FULL-SCALE DEVELOPMENT (FSD)

Alt 1: Incremental Development - Design completeness and reliability confirmed prior to production.

Alt 2: Partial Concurrency - The initiation of significant tasks related to production (without a complete first lot order) prior to the end of FSD.

Alt 3: Full Concurrency - Production begins prior to the completion of FSD with a complete first lot order.

<u>NOTE</u>: In this context, concurrency is characterized by the initiation of production-related tasks prior to the completion of FSD. The <u>degree</u> of concurrency employed in specific cases may vary from a small contract which holds the contractor's technical staff together, to a complete first lot order.

RATING SCALE

For each question, which corresponds to a given state of technical risk, you are asked to rate the strategy alternatives on a numerical scale which indicates how successful you feel the strategy alternative would be at reducing risk as described. The rating scale is as follows:

Rating	Definition
1	Alternative is incapable of reducing risk as described.
3	Alternative has a slight change of reducing risk as described.
5	Alternative has a 50/50 chance of reducing risk as described.
7	Alternative has an excellent chance of reducing risk as described.
9	Alternative will certainly reduce risk as described.
2,4,6,8	Intermediate values to accommodate compromise between the above values.

TECHNICAL RISK

For the purpose of this survey, technical risk is divided into three generic categories:

- <u>Level of Technology Advance (Hardware)</u>

  The existing level of technology in industry is constantly subject to change. An item considered to require new and radically different system design today may well be considered contemporary technology in a few years. The concept embodied in this category is the magnitude of the technology increase over the existing state-of-the-art.

- <u>Degree of Required System Integration</u>

  A large weapon system with many complex internal and external interfaces is a high-technology risk program; not necessarily because it embodies advanced technology, but because it is vulnerable to a large number of error sources.

- <u>Level of Software Dependency</u>

  A weapon system using off-the-shelf components with few intefaces may stll be dependent on a large computer software development effort. If the software is critical to the operation of the system, its development could pace the development of the entire system.

Within each category, five degrees of technical risk have been defined, ranging from low-risk (A) to a high-risk (E) situation. The definitions of these degree levels are as follows:

<u>Cat 1: Level of Technology Advance (Hardware)</u>

<u>Level</u>

A - <u>None</u> (shelf item)

B - <u>Minor</u> development required (at least one subsystem needs some improvement)

C - <u>Moderate</u> development required (at least one subsystem requires major improvements)

D - <u>Major</u> development required (several subsystems require major improvements)

E - <u>Total</u> redesign (all new technology must be developed).

Cat 2: Degree of Required System Integration

Level

A - None (item(s) can be "plugged in")

B - Minor redesign (at least one interface needs some redesign)

C - Moderate redesign required (at least one interface needs major redesign)

D - Major redesign (several interfaces need major redesign)

E - Total redesign (all interfaces must be totally redesigned)

Cat 3: Level of Software Dependency

Level

A - None (delays cause no disruption of hardware development)

B - Minor (delays cause slight disruption of hardware development)

C - Moderate (delays cause moderate disruption of hardware development)

D - Major (delays cause major disruption of hardware development)

E - Total (magnitude of effort so large that delays cause total disruption of hardware development)

EXAMPLE:

Phase: D&V

Risk Category: Level of Technology Advance

State: Perceived Pre-phase Status -- Total Redesign
Desired End-Phase Status -- Moderate Development required

If, based upon your experience and judgment, you feel that contract definition is incapable of achieving the desired result, that subsystem/component development has a very slight chance, and that a system prototype has an excellent chance of achieving the desired result, the question would be answered as follows:

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Contract Definition	Subsystem/ Component Development	System Prototype
Total Redesign	Moderate Development required	1	2	7

RISK ASSESSMENT

QUESTIONNAIRE

RATING SCALE

Rating	Definition
1	Alternative is incapable of reducing risk as described
3	Alternative has a slight chance of reducing risk as described
5	Alternative has a 50/50 chance of reducing risk as described
7	Alternative has an excellent chance of reducing risk as described
9	Alternative will certainly reduce risk as described
2,4,6,8	Intermediate values to accommodate compromise between the above values

LEVEL OF TECHNOLOGY ADVANCE (HARDWARE)

Level

A - None (shelf item)

B - Minor development required (at least one subsystem needs some improvement)

C - Moderate development required (at least one subsystem requires major improvements)

D - Major development required (several subsystems require major improvements)

E - Total redesign (all new technology must be developed).

ALTERNATIVES

Demonstration and Validation (D&V) Phase

- Contract Definition - Short, intense planning and evaluation to determine cost, schedule, performance specification, management technique, etc., for FSD phase.
- Subsystem and Component Development - Critical elements of a system are developed and major subsystems designed and tested.
- System Prototype - Design, build, and test proposed end item (pre-production prototype).

Full-Scale Development (FSD) Phase

- Incremental Development - Design completeness and reliability confirmed prior to production.
- Partial Concurrency - The initiation of significant tasks related to production (without a complete first lot order) prior to the end of FSD.
- Full Concurrency - Production begins prior to the completion of FSD with a complete first lot order.

RISK CATEGORY: LEVEL OF TECHNOLOGY ADVANCE

DEMONSTRATION AND VALIDATION PHASE

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Contract Definition	Subsystem/ Component Development	System Prototype
Total redesign	Moderate development required			
Major development required	Moderate development required			
Total redesign	Minor development required			
Major development required	Minor development required			
Moderate development required	Minor development required			

FULL-SCALE DEVELOPMENT PHASE

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Full Concurrency	Partial Concurrency	Incremental
Major development required	Minor development required			
Major development required	No new knowledge required			
Moderate development required	Minor development required			
Moderate development required	No new knowledge required			
Minor development required	No new knowledge required			

RATING SCALE	
Rating	**Definition**
1	Alternative is incapable of reducing risk as described
3	Alternative has a slight chance of reducing risk as described
5	Alternative has a 50/50 chance of reducing risk as described
7	Alternative has an excellent chance of reducing risk as described
9	Alternative will certainly reduce risk as described
2,4,6,8	Intermediate values to accommodate compromise between the above values

DEGREE OF REQUIRED SYSTEM INTEGRATION

Level

A - None (item(s) can be "plugged in")

B - Minor redesign (at least one interface needs some redesign)

C - Moderate redesign required (at least one interface needs major redesign)

D - Major redesign (several interfaces need major redesign)

E - Total redesign (all interfaces must be totally redesigned).

ALTERNATIVES

Demonstration and Validation (D&V) Phase	Full-Scale Development (FSD) Phase
• Contract Definition - Short, intense planning and evaluation to determine cost, schedule, performance specification, management technique, etc., for FSD phase.	• Incremental Development - Design completeness and reliability confirmed prior to production.
• Subsystem and Component Development - Critical elements of a system are developed and major subsystems designed and tested.	• Partial Concurrency - The initiation of significant tasks related to production (without a complete first lot order) prior to the end of FSD.
• System Prototype - Design, build, and test proposed end item (pre-production prototype).	• Full Concurrency - Production begins prior to the completion of FSD with a complete first lot order.

RISK CATEGORY: DEGREE OF REQUIRED SYSTEM INTEGRATION

DEMONSTRATION AND VALIDATION PHASE

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Contract Definition	Subsystem/ Component Development	System Prototype
All interfaces must be totally redesigned	At least one interface needs major redesigned			
Several interfaces need major redesign	At least one interface needs major redesign			
All interfaces must be totally redesigned	At least one interface needs some redesigned			
Several interfaces need major redesign	At least one interface needs some redesign			
At least one interface needs major redesign	At least one interface needs some redesign			

FULL-SCALE DEVELOPMENT PHASE

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Full Concurrency	Partial Concurrency	Incremental
Several interfaces need major redesign	At least one interface needs some redesign			
Several interfaces need major redesign	No redesign required			
At least one interface needs major redesign	At least one interface needs some redesign			
At least one interface needs major redesign	No redesign required			
At least one interface needs some redesign	No redesign required			

RATING SCALE

Rating	Definition
1	Alternative is incapable of reducing risk as described
3	Alternative has a slight chance of reducing risk as described
5	Alternative has a 50/50 chance of reducing risk as described
7	Alternative has an excellent chance of reducing risk as described
9	Alternative will certainly reduce risk as described
2,4,6,8	Intermediate values to accommodate compromise between the above values

LEVEL OF SOFTWARE DEPENDENCY

<u>Level</u>

A - <u>None</u> (delays cause no disruption of hardware development)

B - <u>Minor</u> (delays cause slight disruption of hardware development)

C - <u>Moderate</u> (delays cause moderate disruption of hardware development)

D - <u>Major</u> (delays cause major disruption of hardware development)

E - <u>Total</u> - (magnitude of effort so large that delays cause total disruption of hardware development).

ALTERNATIVES

<u>Demonstration and Validation (D&V) Phase</u>

- Contract Definition - Short, intense planning and evaluation to determine cost, schedule, performance specification, management technique, etc., for FSD phase.
- Subsystem and Component Development - Critical elements of a system are developed and major subsystems designed and tested.
- System Prototype - Design, build, and test proposed end item (pre-production prototype).

<u>Full-Scale Development (FSD) Phase</u>

- Incremental Development - Design completeness and reliability confirmed prior to production.
- Partial Concurrency - The initiation of significant tasks related to production (without a complete first lot order) prior to the end of FSD.
- Full Concurrency - Production begins prior to the completion of FSD with a complete first lot order.

RISK CATEGORY: LEVEL OF SOFTWARE DEPENDENCY

DEMONSTRATION AND VALIDATION PHASE

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Contract Definition	Subsystem/ Component Development	System Prototype
Total disruption	Moderate disruption			
Major disruption	Moderate disruption			
Total disruption	Slight disruption			
Major disruption	Slight disruption			
Moderate disruption	Slight disruption			

FULL-SCALE DEVELOPMENT PHASE

STATE		ALTERNATIVES		
Perceived Pre-Phase Status	Desired End-Phase Status	Full Concurrency	Partial Concurrency	Incremental
Major disruption	Slight disruption			
Major disruption	No disruption			
Moderate disruption	Slight disruption			
Moderate disruption	No disruption			
Slight disruption	No disruption			